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Considerations for deep-sea environmental impact research on marine carbon dioxide removal

Key messages

- The ecology of the deep ocean has been poorly considered and represented in discussion of mCDR and there are many uncertainties about the scale and degree of impacts, which will vary by technology type.
- The deep ocean is home to diverse and unique species, habitats and ecosystems that play important roles in the carbon cycle and other Earth systems.
- Special features of deep-sea ecosystems pose unique challenges and require distinct approaches for assessing mCDR consequences.
- More research is needed on the impacts of any mCDR proposals involving the deep ocean and their efficacy as a potential climate change solution.

Background

As society recognizes the urgent need to reduce atmospheric greenhouse gas levels to limit global warming, industries and nations are increasingly considering **marine carbon dioxide removal (mCDR)**. A common feature of many mCDR initiatives is that the deep ocean is indicated as a primary storage region for removed carbon. Frequently, the deep ocean is presented as a 'black box' in these proposals, with no additional information on the habitats, taxa or ecosystem processes that may be impacted by added carbon. Contrary to the impression given by such proposals, **deep-sea ecosystems are home to a vast array of diverse and unique species**, many of which play important roles in the carbon cycle and other Earth systems and functions. It is essential that risks to these deep-sea environments are centrally included in research on potential impacts of mCDR.

Unique deep-sea features and relevant processes

The deep ocean is a mosaic of different ecosystems and habitats (e.g., slopes, biogenic reefs, chemosynthetic ecosystems, seamounts, canyons, basins, abyssal plains, trenches) each hosting unique ecological communities **sensitive to environmental change**. Many deep-sea organisms grow slowly, live long, mature late and produce few offspring, slowing recovery from disturbance, such as from mCDR. Most deep-sea ecosystems are dependent on organic matter sinking from the ocean surface, and are **highly connected** to the surface and each other by vertical and horizontal migrations of organisms. These ecosystems can be disturbed by changes in surface production and subsequent effects of changed ocean chemistry, smothering or burial, induced by mCDR. Most species in the deep ocean remain unknown, and many are rare. All these features of the deep ocean make the **effects of mCDR uncertain and difficult to constrain**.

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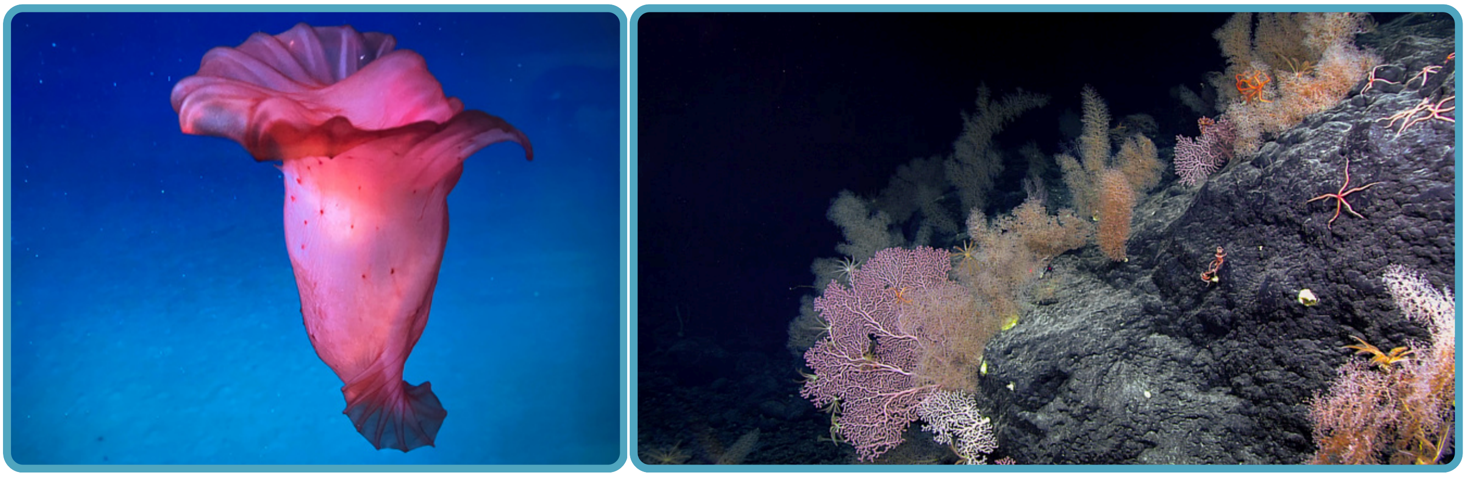

An Enypniastes eximia *sea cucumber (left) and deep-sea coral garden (right), exemplifying some of the rich biodiversity in the deep ocean that could be impacted by mCDR. Images courtesy of Lisa Levin and Schmidt Ocean Institute, and the NOAA Office of Ocean Exploration and Research.*

Cumulative and combined effects of mCDR in the deep sea

Individual impacts of mCDR will add to impacts from other ongoing human activities such as oil and gas extraction, fisheries, tourism, waste disposal, cable laying, scientific research and climate change, as well as emerging or potential activities such as deep-seabed mining and bioprospecting. Possible **cumulative and synergistic effects should be considered** when evaluating mCDR proposals to support sustainable management of the affected ecosystems.

Approaches for evaluating mCDR impacts in the deep sea

- **Laboratory experiments** addressing mCDR impacts are limited to small taxa and the few culturable microbes. Most deep-sea assemblages cannot survive at surface pressure and thus are not amenable to experimentation. Currently, laboratory best practices for Ocean Alkalinity Enhancement (OAE)/mCDR focus on pelagic species.
- **Mesocosms** offer an integrated approach to study ecosystem diversity and function but, as with laboratory experiments, most deep-sea assemblages will not survive in an unpressurized mesocosm.
- **Field experiments** on deep-sea impacts have yet to be conducted for many mCDR technologies because of the challenge of upscaling approaches and tracking exported carbon at relevant space and time scales. Permitting and high cost for conducting experiments are additional challenges. Nevertheless, manipulative field experiments that simulate elevated CO_2 levels can inform on potential mCDR consequences.
- **Models,** both conceptual and mathematical, can be powerful tools to evaluate mCDR impacts in the deep ocean under different biological or technological scenarios where knowledge is limited and uncertainty is high. Major challenges include scalability and data availability at relevant resolutions for model evaluation.
- **Natural analogs** to mCDR deployments can be used to anticipate mCDR impacts. Examples include areas of upwelling, natural iron fertilization, or the Sargassum Belt for organic matter flux, areas of natural CO_2 venting for carbon capture and storage, and naturally alkaline sites for ocean alkalinity enhancement.

Social, governance and equity implications

The deep ocean is interlinked with people and societal processes. Research on impacts associated with mCDR requires consideration of social governance and intergenerational equity due to potential local and regional scale effects on fisheries and other ocean-based economies and global climate regulation disruption. Special attention must be given to Indigenous Peoples, Low- or Middle-Income Countries (LMICs) and Small Island Developing States (SIDS) to ensure any initiatives are equitable and have public support locally and globally.

Deep-sea impact considerations for mCDR methods

Method	Description	Deep-sea impact considerations
Direct Ocean Capture	Removal of dissolved inorganic carbon (DIC) from seawater and return of the DIC-depleted water to the ocean where it can uptake additional anthropogenic CO_2.	Depth, timing and volume of water intake are important for assessing mortality due to entrainment of diel vertical migrators and planktonic larval stages of deep-sea organisms. Precipitated carbonate minerals in returned seawater could rain out of the surface ocean and flux down into the deep ocean.
Ocean Alkalinity Enhancement (OAE)	Enhancement of ocean alkalinity either through alkaline mineral addition to seawater or through electrochemical methods, so the seawater can uptake additional anthropogenic CO_2.	Mineral addition may cause clogging of respiratory and filtration structures of deep-sea organisms by small particles, leaching of trace metals, and secondary food-web impacts of shading. Electrochemical OAE may cause entrainment from water intake and secondary precipitation of carbonate minerals.
Organic Matter Sinking	Sinking of organic material, such as brown seaweeds, agricultural crop waste, or wood waste, into the deep ocean.	Amount, timing, location, underlying oxygen conditions, and source of organic material are important considerations. Risks include smothering and seafloor habitat modification from added organic matter, increased bacterial respiration causing local oxygen loss and acidification, and pesticide exposure from agricultural material.
Ocean Fertilization	Stimulation of phytoplankton production and exportation of additional particulate organic carbon into the deep ocean.	Increased particulate organic carbon flux can lead to oxygen loss and acidification. Smaller particles mean slower flux, so more impacts to deep pelagic (i.e. water column) organisms than with organic matter sinking. Out-of-season sinking of organic matter can disrupt reproductive cycles and lead to changes in life-history phenology.
Carbon Capture and Storage	Capture of CO_2 directly from the atmosphere or from seawater and storage of the captured CO2 in geologic reservoirs such as the seabed.	Installation of CO_2 injection infrastructure may disrupt seafloor habitats, resulting in habitat loss and fragmentation, and impact ecosystem functions such as nutrient cycling and carbon sequestration. CO_2 leakage from storage reservoirs and subsequent organismal exposure to low pH conditions is also a concern.

Cost, access and research challenges

Deep-sea research, including on impacts of mCDR as a potential climate solution, faces significant financial challenges. Currently, most mCDR research is led by businesses or academics from industrialized nations, excluding LMICs, and particularly SIDS. Lack of inclusivity is also a concern as commercial interests in carbon credits from mCDR expand, primarily benefiting companies while offering limited environmental gains to LMICs and Indigenous Peoples. Before commercializing mCDR technologies, **more research is needed to address risks and establish equitable governance frameworks**. Additionally, a robust system for **Monitoring, Reporting and Verification (MRV)** is critical to ensure transparent and effective management of mCDR projects, fair distribution of benefits and undisputed links to effective CO_2 removal. In the absence of sufficient research on the implementation of mCDR, side effects may worsen environmental problems making them more expensive to solve. Any short-term gains from selling carbon credits will be lost in the long run while deep-sea ecosystems are likely to be harmed in the process.

References

This policy brief is based on a research paper titled "General considerations for deep-sea environmental impact research of mCDR", in preparation by Gallo et al.

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About DOSI

The Deep-Ocean Stewardship Initiative is a global network of experts that integrate science, technology, policy, law and economics to advise on ecosystem-based management of resource use in the deep ocean and strategies to maintain the integrity of deep-ocean ecosystems within and beyond national jurisdiction.

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